Integrated Solar City: Application of the Ecological Risk Assessment Paradigm to Inform Reclamation

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Abstract

The Integrated Solar City (ISC) is a large solar project that has been proposed for development in the western state of Gujarat, India. The project will be the largest solar project in the world. It will require the use of large land resources to construct. An ecological risk assessment (ERA) is used to assess potential impacts from project construction and operation. Previous research suggests that a solar project of this scale would require the removal of vegetation along with other negative effects on vegetation and soil. The ERA was used to lay out a revegetation plan that would help mitigate the long-term environmental impacts in the Banaskantha and Kachchh regions of Gujarat, India.

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Introduction

Statement of the Problem

The Integrated Solar City (ISC) is a step towards bolstering a clean energy economy in Gujarat, India. The ISC would produce 5 gigawatt (GW) of power, which is over 5 times the size of the largest current solar project, located in the Mojave Desert of the United States (Mcdermott 2008). India is a large developing country with immense energy needs. However, if only one-half of one percent of India's land were converted to solar photovoltaic panels (PV), it would produce sufficient electricity to power India by the year 2030. This is based on growing energy consumption trends and solar radiation data in India (PV Group 2009).

Solar energy technologies are a very clean form of electricity production. They stand to benefit the people of India, in particular if the ISC is developed. However, it is not clear what construction and operational effects there could be on the natural environment, specifically with respect to vegetation and soils. The two sites under consideration for selection within Gujarat, Kachchh and Banaskantha, are fragile desert ecosystems. (PV Group 2009). Careful consideration must be given to any construction project in these regions with respect to soil, water, and land resources so that native vegetation can thrive.

This capstone will analyze the ongoing study of vegetation plots at the large solar array at the National Wind Technology Center (NWTC), National

Renewable Energy Laboratory (NREL) in Golden, Colorado. The NREL study is relevant to the ISC. It will help with the analysis of potential environmental impacts of large-scale solar project construction. The study at NREL is similar to what is needed for the ISC, studying management practices that are needed to assure the co-existence of native vegetation and solar array efficiency. These data will help develop the ecological risk assessment (ERA) that will be key to determining best management practices (BMPs) to promote vegetation health while moving forward with implementation of the ISC.

Thesis Statement

An ERA will be used as a tool to assess potential risks to vegetation during ISC construction and its subsequent operation, providing guidance for the revegetation of the ISC project as well as revegetation of future solar complexes.

Goal and Objective

The analysis will focus on creating an ERA for vegetation at the proposed ISC in Gujarat, India. An ERA is a flexible process that analyzes the potential for physical, chemical, or biological stressors to exist, which could elicit adverse effects on the vegetation of ISC (Hope 2006). The goal of the capstone project is to access ways to protect native vegetation during the construction of the ISC, and to aid revegetation of the site after construction is complete. This information can then be applied to other large solar facilities developed in desert ecosystems. We do not truly know the implications of these large projects on native vegetation and soils, but we do know that solar projects are being rapidly developed, particularly in India, to keep pace with energy consumption (Bhattacharya 2009). It is important to have methods in place so that the natural environment is not exhausted from the recent explosion in renewable energy technologies.

The objective is to develop best management practices that can be viewed and referred to by parties involved in the ISC. The best management practices should be referred to by policy makers, government officials, engineers, scientists, students, researchers, and any parties interested in the effects on vegetation from large solar projects. The best management practices will be directly related to how the long-term effects on vegetation and soils can be mitigated by taking necessary steps during and after the construction phase of a large solar project. The best management practices will also have step-by-step directions of how to best implement a revegetation plan.

Significance

The significance of this capstone project will be to contribute important information on ways to protect and enhance native vegetation where solar array installations are installed. Protecting native vegetation is important to limiting soil erosion and preserving wildlife habitat.

There is limited research on impacts to vegetation from solar project development. The ERA for the ISC will analyze specific risk factors that will help bring attention to the fact that large solar projects may have an effect on vegetation. It will also help serve as a guideline for the construction of large solar projects so that developers will exercise careful consideration during the planning and construction phase. This will be important for minimal environmental effects to persist.

Literature Review

Solar Energy Technologies

Solar energy technologies are an important part of the future. Scientific projections for the next forty years suggest that 50 percent of the warming that will occur will come directly from the energy sector (Tsoutsos et al. 2005). India has the second highest population of any country in the world, so the relationship between how India satisfies its energy needs and the environment will always be an important issue. In fact, it is safe to say that climate change is itself an energy issue, and only drastic measures to reduce carbon dioxide (CO_2) emissions in the coming years will do anything to abate warming (Allen and Christensen 1990).

Depending on the type of solar energy technology, it is possible to achieve near zero greenhouse gas emissions, while also having near zero risk of gaseous or liquid chemical substances leaking. Also, the risks for radioactive materials affecting the environment are non-existent (National Renewable Energy Laboratory 2010). Despite being expensive in some cases to implement, there is the potential to reap economic rewards from developing a new clean energy economy, and particularly utilizing solar energy technologies. These could provide a return on investment in developing countries, like India, diminishing the need to import energy while also creating jobs (Allen and Christensen 1990). The project is narrowed down to two potential sites, both found in the western part of Gujarat, straddling the border of Pakistan. The ISC will either employ solar photovoltaic (PV) or solar thermal technology (Mcdermott 2008).

Solar Thermal

Solar thermal is a solar energy technology that utilizes the thermal energy collected from the sun to create steam that drives a piston. The pistons are driven by super-heated water created by solar collectors (National Renewable Energy Laboratory 2010). Prior analysis of solar thermal technology projects is quite limited due to limited deployment to date (Tsoutsos et al. 2005). However, certain environmental effects are known. Manufacturing of solar energy technologies produces greenhouse gas emissions of CO_2, nitric oxide (NO_x), and sulfur dioxide (SO_2). During the construction phase, as with any construction project, there are likely to be noticeable impacts to the environment (Tsoutsos et al. 2003). These impacts could include effects on landscape, ecosystem and habitats, noise and visual pollution, and impacts from construction vehicles in the form of greenhouse gas emissions. Despite these effects, solar thermal technology is considered to be one of the most efficient with regard to land use. This is why they are considered a valuable option for desert areas, where the soil and habitat is quite fragile. If careful attention is paid during the planning, construction, and operation phase, the effects on vegetation, soil, and habitat can be minimized (Tsoutsos et al. 2003).

While solar thermal has yet to be deployed on a large-scale, there have been an increasing amount of contracts applied for by companies seeking to build solar thermal plants. The Bright Source Energy Corporation Vice President of Marketing and Business believes that the market will favor solar thermal in the future, and that solar thermal can be implemented on a much larger scale that is up to speed with our future energy needs, while also keeping costs low (Wang 2009).

Ivanpah Solar Energy Complex

A more detailed plan for a solar thermal energy complex, one of the two options for the ISC, is the Bright Source Ivanpah solar energy complex (figures 1 and 2). The site has been planned for the desert of California, 4.5 miles from Primm, Nevada. The solar complex will generate 400 MW, or roughly 8 percent of the energy potential at the ISC. Despite the relatively small amount of generation capacity compared to the ISC, it is valuable to compare the two sites to determine what prior measures have been taken for site selection of large solar thermal complexes.

Figure 1 An Image of the Ivanpah site before the construction of the solar complex (Save Ivanpah Valley 2009)

Figure 2 An image depicting what the Ivanpah valley will look like after the construction of the solar complex (Save Ivanpah Valley 2009)

Ivanpah is on schedule to be built ahead of the ISC. Ivanpah will be capable of generating enough power to serve 140,000 homes with electricity. Ivanpah will be comprised of three separate plants built in phases between 2010 and 2013 (Wang 2009). The project plan details the amount of CO_2 the plant will save, among other environmental benefits. However, the negative impacts to the environment are not found in the project plan. Further research is needed to evaluate these potential impacts.

The concerns with large solar thermal projects are with respect to land resources. Land resources will need to be graded to no more than one percent slope to maximize the output of the solar technology and native vegetation will need to be removed. Grading the land, in some cases as flat as one percent, can help increase the potential MW at a solar site (Beatty 2010).

The Ivanpah site will cover an area of roughly 1.25 square miles. Rather than grading the land, Ivanpah will use poles that will be driven into the ground, which will support the heliostats, or large mirrors for solar reflection. Bright Source maintains that this will reduce the need to grade the land, and also will use fewer concrete pads, or blocks for stabilizing the solar panels. The result is less land degradation and more area for vegetation to persist (Bright Source Energy 2009).

Those that oppose the development of the solar complex, like the group Save Ivanpah Valley, argue that Ivanpah would require expansive land resources, which would require grading to clear the way for proper construction of the complex (Save Ivanpah Valley 2009). The Preliminary Staff Assessment (PSA) prepared by the California Energy Commission suggests that any implementation of Ivanpah would require expansive land grading that would result in major disturbances to the local ecosystem leading to increased erosion and offsite sedimentation. The grading would require the complete removal of all vegetation lying within the area of the solar thermal complex, and need to reach a grade of less than 5 percent. The PSA does not include any information about what mitigation measures will be taken to save vegetation. Some believe the PSA was written prematurely without proper attention given to the delicate ecosystem in the Mojave Desert (Save Ivanpah Valley 2009).

This also does not answer the question of what will be done for vegetation regarding replanting native species of vegetation in areas where they were completely removed. And, if replanted, how will the native species respond to an environment now shaded by large heliostats? A long-term research study at the site would be needed to determine the success of native species under the heliostats. The same holds true for any ISC project. However, the ISC will require roughly ten times the land area as the Ivanpah project will need, so questions prior to construction over the long-term damage to native vegetation are more critical.

Solar PV

Solar PV technology is the alternative to solar thermal technology at the ISC. Solar PV converts sunlight directly into electricity. PV literally means 'photons to voltage', an effect that was discovered in 1954 when scientists found that silicon, when mixed with sunlight, naturally created a small electrical charge (National Renewable Energy Laboratory 2010). Solar PV is a much more popular solar energy technology, although it is still in its initial stage of deployment in India (Bhattacharya 2009). This is mostly due to the fact that there are many more solar PV applications, although most are on a smaller, piece-by-piece residential and commercial scale. However, if only a half of one percent of India’s land were converted to solar PV, it would produce enough electricity to power India in the year 2030. This is based on growing energy consumption trends and solar radiation data in India (PV Group 2009).

Solar PV has the same environmental impacts as solar thermal technologies with respect to land use, ecosystem and habitat, noise and visual pollution, and emissions from construction activities. Both systems will impact the natural environment at the construction phase. However, it is not clear which one is more advantageous in the long term. Heliostats used for solar thermal and solar panels used for solar PV are installed similarly, in long rows, shading the ground beneath. Any vegetation living in and around either technology will have to overcome long-term shaded conditions.

Solar PV does not require the use of water resources for cooling, important to factor in considering the majority of solar energy technology projects are placed in areas where there is plenty of solar radiance and typically arid to semi-arid climates, like Gujarat, India. However, solar PV projects are quite energy intensive, requiring a large quantity of materials to be built. The information on impacts to soil and vegetation are limited. Not enough is known about these two technologies due to such recent deployment.

Kings County, California Solar PV project

The Kings County solar PV project, similar in scale to Ivanpah, is a solar PV project planned for the Mohave desert of southern California (figure 3). The project will inhabit a fragile desert ecosystem similar to that found in Gujarat, India. The project is part of a U.S.- China partnership to build solar PV projects in the United States and China. California's Canergy International with China's Guodian Corporation signed the agreement on April 21, 2009. The project was also agreed upon, and signed by California Governor Arnold Schwarzenegger (Lindt 2010). The 500 MW solar PV power plant will cover roughly 3-4 square miles, or roughly 2,500-3,000 acres.

Figure 3 Future location of the Kings County solar photovoltaic project in California (Lindt 2010)

The 500 MW complex will have the potential to power approximately 100,000 households. The Ivanpah and Kings County projects will both supply nearly the same amount of power, yet the Kings County project would be roughly 3 times the size of the Ivanpah solar thermal energy complex. The reason for this is not fully understood, but this is a key point to consider for the ISC, where reducing impacts to vegetation is important.

Also, it appears that both sites will be capable of supplying roughly the same amount of power. There is not much known with respect to cost of construction and long-term costs of operation, but this brings up an important point. The ISC, at its size, will need to consider any technology that would reduce the amount of land area needed for construction.

There was no evidence of a formal environmental impact statement (EIS) process conducted at the Kings County site. The conclusions presented about land use and potential stressors were supported by reviewing previous research on solar complex construction along with general construction in fragile desert ecosystems (Save Ivanpah Valley 2009). Based on information from the NREL solar array, which utilizes solar PV technology, land grading will be required similarly to the Ivanpah solar thermal energy complex. The need to remove vegetation for construction and also remove the threat of fire is needed to ensure the success of both solar PV and solar thermal plants.

At NREL, the land was graded to one percent slope in order to optimize the solar PV cells, a much more substantial grading than the Ivanpah site, which requires a less than 5 percent grade. Both cases suggest that land grading will happen at the ISC if a solar plant of either technology is to be employed. While the information on solar complex construction in India is limited, there is relevant information on the effects on vegetation from major construction activities at surface mines. These surface mines created wastelands, where new studies are being conducted to determine the viability of revegetation.

Mine Reclamation in Rajasthan, India

Surface mining is an industry that is particularly harmful to native vegetation. The information gained from mined-land reclamation in India should be applicable to the ISC project in assessing vegetation damage and recovery.

Spread out over 700,000 hectares in India, surface mining requires the removal of local vegetation, and can disturb the soil profile as well as compact the soil (Sharma et al. 1999). These are activities similar to the construction of a solar complex, and with the reclamation study taking place in the same ecosystem as Banaskantha and Kachchh in western India, the methods implemented within the mine reclamation study are important to the ISC project.

Rajasthan is considered an arid to semi-arid climate, much like Banaskantha and Kachchh, receiving about 370 mm of rain in 20 days spread out over an 11-week period. Severe droughts occur frequently when monsoon rainfall becomes erratic within that period (Gough et al. 1992). Old abandoned mine sites were taking up large areas of land, with little to no vegetation left in their place.

Researchers suggest a method for developing a revegetation plan that aim at safeguarding the environment from further degradation that may have been caused during construction and operation. Mine construction, like solar complex construction, is a very intensive process that places stress on the natural environment.

In both cases, the surface layer of topsoil is scraped off and removed, diminishing the chances of vegetation to re-grow. Indian arid soils are often quite shallow with high salinity content. Mining efforts take the shallow soil profile and often remove it entirely. Solar energy construction would require a similar process for removal. This leaves behind subsoil that lacks the same nutrient content of the top soil. The impoverished soil can also become colonized by weeds that colonize in when the native plants are unsuccessful at growing on the subsoil (Sharma et al. 1997).

The intended outcome of the study was a revegetation plan for the arid to semi-arid climate in Rajasthan by improving soil profile, planting native species of grass, shrubs, and trees, and harvesting rainwater for the species of plant (Sharma et al. 1999). In Banaskantha and Kachchh, the soil profile is mostly shallow, like in Rajasthan. Also, the plant species selected for revegetation must be successful without the continued input of water and fertilizer. The selected plants must also be able to withstand animal grazing. The primary focus was a vegetative cover that was diverse and could enhance the soil with nutrients on its own (Sharma et al. 1997). This should be the same intended purpose for a revegetation of the ISC upon completing the construction phase.

Unlike the U.S., India does not have strict reclamation laws for wastelands. Overuse in the form of overgrazing, fuelwood harvesting, soil erosion, desertification, and salinization from improper irrigation are all factors that affect the soil and degrade the land, and are all factors that will place added stress to the ISC site. Inevitably, the land cannot sustain native species of plants. Studies of this nature are important to protect against the spread of desertified wastelands in Rajasthan and the rest of India. The ISC could risk turning the site of the ISC into a wasteland.

NREL Solar Array Study

At NREL in Golden, Colorado, the Environmental Health and Safety (EHS) department under the direction of its senior wildlife biologist is in the early stages of testing vegetation plots at the NWTC solar array. This unique study is seeking answers to long-term effects on native vegetation from the construction and implementation of solar arrays. This information will provide input into the ERA for the ISC.

Solar arrays are usually large fields of solar panels. In some cases, soils at construction sites are sterilized to clear vegetation to put the arrays on solid ground (Beatty 2010). The very existence of solar arrays can have an effect on everything that grows beneath it due to the increase of shading, particularly in a place like Golden, Colorado or Gujarat, India where sunshine is plentiful. Also, in the case of tracking arrays, the ground may need to be graded almost completely flat. In all cases, significant stress is put on native vegetation at solar array sites. As a result, soil erosion can be problematic, compromising the quality of vegetation and wildlife habitat.

In the case of the NWTC solar array, the ground was graded to a 1% slope (Beatty 2010). In order to accomplish this, the pre-existing native grassland had to be eliminated. One acre of land was retained at the NWTC for the vegetation test plots. The important question that NREL researchers are trying to answer is: What is a proper native species mix that can be successful in co-existing with a solar array while having low biomass, an ability to outcompete weeds, require very little water, and also not grow to a height that will restrict the functioning of the solar arrays? Lastly, the plant species must be native vegetation, needed to reduce the amount of soil and wind erosion (Beatty 2010). Native vegetation assures that the species is properly adapted to the environment, and can be successful long-term, outcompeting weeds and coping with harsh climatic conditions.

The NREL team decided on four plant mixtures and three mulch/nurse crop treatments, or growing techniques. These were coded and evenly planted within the vegetation test plots. The species consisted of mostly grasses that were native to the grassland that existed prior to the NWTC array. They were assigned labels and were put into a plot design. The plot design was in the form of rows, with the species mix and mulch/nurse crop treatments different in each plot. This is what is known as a factorial design, and allows NREL to analyze multiple independent variables simultaneously

(Beatty 2010). With that information, the best fitting species mix and mulch/crop treatment can be replicated to best match native vegetation to the location of a solar array.

The study at NREL was initiated in late April of 2010. The first monitoring of the test plots occurred in the beginning of June and yielded no results. NREL hopes there will be results by late summer as the summer season progresses. NREL also hopes that their vegetative study will help others ask similar questions about the effects of solar projects on the vegetation of surrounding areas. The outcomes yielded from the study, through testing different plant species, will help project managers at sites like the ISC design and implement their own revegetation plan. NREL researchers believe that the use of native vegetation may even help the success of solar arrays by mitigating the effects of 'heat sinks', or areas where heat is trapped (Beatty 2010). These heat sinks may produce damaging temperatures, and prolonged exposure to high temperatures may damage solar array equipment over time.

Design and Implementation

Banaskantha and Kachchh Study Sites

Like Colorado, the state of Gujarat has mostly an arid to semi-arid climate. The Gir National Park, located in the western part of Gujarat, is marked by only three seasons: summer, winter, and monsoon. Of these, summer is the longest, and has temperatures ranging from 10 to 45 degrees

Celsius (50 to 113 degrees Fahrenheit). The topography in the northwestern part of the state is mostly low hills, and the vegetation has adapted to a warm climate. In both Banaskantha and Kachchh, there are very few forested areas. The dominant terrain is grassland and plains, which are generally quite dry. Vegetation is most plentiful in coastal Kachchh, and in low areas near streams, protected from direct sunlight.

Both regions receive little rainfall. The Kachchh region receives much less rainfall than Banaskantha, and is classified as an arid region. It receives around 300 mm of rain per year, almost entirely between July and September (Gujarat Ecology Commission 1996). The Banaskantha region receives between 425-716 mm of rainfall a year, and is classified as a semi-arid region. Kachchh only has 13 rainy days a year, meaning a day where it receives 2.5 mm or more of rainfall, while Banaskantha receives 25 rainy days a year. This means that solar radiance is extremely high in both regions, with over 300 days a year of sun. The amount of rainfall is important to consider when deciding which native species would be best suited for an ISC site in either Kachchh or Banaskantha.

There are frequent droughts. These droughts are compounded by an increased need for water for human activities in order to keep agriculture, livestock, and humans hydrated. While 18 percent of the Banaskantha region and the entire Kachchh region are considered an arid to semi-arid zone, the combination of low rainfall, climate change, and human activities dependent upon water have created a spreading arid zone in both regions (Gujarat Ecology Commission 1996). Activities that spread the arid zone include major construction and building projects, specifically those that were built without adequate planning or consideration of their site. The ISC would be a major project of this nature. The construction of the ISC has the potential to exacerbate the process of desertification in Banaskantha or Kachchh. Once the ISC site is selected, proper planning will be important to not further any desertification in either region.

Despite being mostly arid to semi-arid zones, Banaskantha and Kachchh are still rich in native species of vegetation. In Kachchh, there are 695 different species of flowering plants, 345 of which are indigenous to the area. The vegetation is generally scrubby, with the Euphorbia Nivulia being the dominant species in drier areas, whereas Acacia tree species are dominant in areas that are less arid. Banyan trees are also distinct to the area (Gir National Park 2010). Neither area is comprised of much forested area, however. Kachchh has 6 percent while Banaskantha has around 5 percent of its land area covered by forest. This leaves a large percentage of grasslands and plains, the most likely place for the ISC site to be built.

Grasslands and plains in arid zones do not have as many species of vegetation compared with other regions of India (Gujarat Ecology Commission 1996). This is, in part, due to the increasing loss of adequate topsoil, and the lack of rainfall along with decreasing adequate topsoil make further compound the extreme conditions.

These regions in Banaskantha and Kachchh are increasingly cleared every year for human needs such as cultivation and farming, a major catalyst for desertification. One of the most destructive human activities is the gathering of wood for fuel (Gujarat Ecology Commission 1996). This clearing of the vegetative cover in both regions leads to erosion and the depletion of topsoil, leading to much less native vegetation.

Both site candidates are very similar. The only notable difference is with respect to precipitation. It is for that reason that this capstone suggests the Banaskantha region for the site of the ISC. While species are able to be successful in both regions, a Banaskantha site gives the plant species a better chance to thrive with added precipitation. Furthermore, added precipitation is also an indicator of added cloud cover. Due to the fact that the solar array will shade plants, adaptation of species to fewer sunny days would mean they could potentially be better equipped to deal with less direct sunlight.

Ecological Risk Assessment Design

The ERA was used to analyze the following thesis statement: Are there any long-term potential effects on the vegetation in Gujarat, India that may occur as a result of the ISC project? An ERA, typically used to analyze chemical contamination, is a flexible process that allows researchers to analyze ecological impacts, in this case the impacts on vegetation at the construction of the ISC. The ERA evaluates what the potential is for human activities to have an effect on the natural environment of an area (63 Federal Register 26,846 [May 14, 1998]).

CERCLA uses the ERA to assess impacts, in addition to assessing liability for ‘injury’, or damages to natural resources. CERCLA’s ERA analyzes the effects on natural resources including land, fish, wildlife, biota, air, water, groundwater, drinking water supplies, and other resources (Hope 2006). Site-specific chemical stressors are the key component. However, the ERA can be used to analyze site-specific stressors placed on vegetation and soil by construction activities at the ISC site.

The ERA is also used in fisheries management. Fisheries management is the practice of analyzing the interaction, structure, and dynamics surrounding interactions with fish habitat (Lackey 1998). Fisheries management requires a process that can identify and analyze many different potential stressors that could be placed on fish within fisheries. This is a difficult task for quality management. To accomplish this, ecological risk assessment is employed, allowing managers to make sense of complex ecological problems by following a process to identify and analyze potential consequences of negative impacts on our natural environment. Like CERCLA, fisheries management typically uses an ERA to analyze chemical contamination (Lackey 1998). However, an ERA is a flexible process that can be extended to evaluation of stressors from physical impacts, like the construction phase at the ISC.

The ERA was used in this capstone to evaluate potential risks and follow through a process of analyzing them to produce a plan that will mitigate the potential stresses placed on the natural environment. The ERA focused specifically on the effects on vegetation. Once analyzed, the effects on vegetation helped develop the revegetation plan that was best suited for the climate in Banaskantha, and takes into account the use of native species that are well adapted to an arid to semi-arid climate.

An ERA uses five main steps: problem formulation; analysis; risk characterization; risk mitigation; and risk monitoring. These steps are fully detailed in the 63 Federal Register 26,846 (May 14, 1998). The problem formulation step is where the problem is fully described. This step integrates previous research with the problem being studied to determine assessment endpoints, or expressions of the environmental value of what is to be protected. This step is also where the analysis plan is developed.

The analysis step involves detailed measurement and analysis of all the relevant stressors in the study, which leads to an exposure profile and stressor-response profile. These profiles are used when studying stressors imposed by chemicals, so they were not constructed within this capstone project. The risk characterization step is where the risk estimation is developed, leading to the risk description. The risk manager receives this, and it is then communicated to the general public.

The risk mitigation step takes the results of the study and uses the information to make mitigation decisions that will protect the assessment endpoints and also make all involved parties satisfied with the final determination. Finally, a risk monitoring step is used if there are follow-up activities needed like long-term monitoring of the success of a revegetation plan. If changes in the success of plant species are measured, effective mitigation measures can be taken to insure long-term success (table 1).

Table 1 Steps to the ERA process with the important details for each step (63 Federal Register 26,846 [May 14, 1998])

Steps to the ERA	Details for each step
1. Problem Formulation	This is where available information is integrated. This results in assessment endpoints and the conceptual model of the ecological risk assessment. An analysis plan results from this first step.
2. Analysis	This step involves measures of exposure, measures of ecosystem and receptor characteristics, and measures of effect. This creates both an exposure analysis and ecological response analysis. From this, an exposure profile and stressor-response profile is developed leading into the final step.
3. Risk Characterization	Here, the risk estimation is developed, leading to the risk description. The results are then communicated to the risk manager, and then on to the public and interested parties.
4. Risk Mitigation	This step is where the risk manager assesses the results of the risk characterization and makes mitigation decisions. A risk manager must consider ecological risks, but also social, economic, political, or legal issues related to his/her decision.
5. Risk Monitoring	Risk managers may consider whether follow-up activities are required. They may decide on risk mitigation measures, then develop a monitoring plan to determine whether the procedures reduced risk or whether ecological recovery is occurring.

The Ecological Risk Assessment for Banaskantha

The ERA for the ISC began with the problem formulation step. This step was used to identify the environmental value of native vegetation in Banaskantha, the selected region. This value is measured by how important it is to be protected so that native vegetation and the ISC can co-exist with minimal stress on one another. This is an important step towards identifying plant species in Banaskantha that are valuable in protecting the soil from desertification, have low biomass protecting the solar technology from fire damage, can outcompete weeds, require little water, are resistant to overgrazing, and also do not grow to a height that will restrict the functioning of the solar arrays.

The analysis plan was also developed in this step. The analysis expanded on the key stresses on the environment noted above. The analysis plan then focused on the three plant species that have been chosen as mitigating the stresses placed on the environment after the construction of the ISC. The risk characterization step expanded on the potential impacts, and described the occurrence of these stressors at the ISC site. Due to the fact that this capstone project does not have the resources to conduct a full ERA, the analysis and risk characterization steps were all conducted within the risk characterization step.

The BMPs exist within both the risk mitigation and risk monitoring steps. These BMPs outline the necessary process for mitigating the environmental effects using a revegetation plan specifically catered to the ISC in the risk mitigation step. In the final step, the BMPs outlined the necessary follow-up activities at the ISC. Follow-up activities may include mitigation measures to increase the effectiveness of plant species at the ISC site that may be reduced by invasive species and weeds, grazing animals, and climatic conditions. Also, the risk monitoring step will help ISC officials with identifying any future negative impacts on the environment with respect to native wildlife, and help mitigate these effects. All of the steps of the ERA are detailed below (table 2).

Table 2 The steps to the ERA detailed specifically for Banaskantha

Steps to the ERA	Details of each step for Banaskantha
1. Problem Formulation	-Identify environmental value of vegetation in Banaskantha -Identifying plant species in Banaskantha that are valuable in protecting the soil from desertification, have low biomass protecting the solar technology from fire damage, can outcompete weeds, require very little water, resistant against overgrazing, and also do not grow to a height that will restrict the functioning of the solar arrays.
2 and 3. Analysis and Risk Characterization	-Expand on the potential impacts -Describe the occurrence of these stressors at the ISC site -Focus on the three plant species that have been chosen as mitigating the stresses placed on the environment after the construction of the ISC.
4. Risk Mitigation	-Determine species selection. -Define BMPs with necessary steps to an ISC revegetation plan.
5. Risk Monitoring	-Identify and mitigate any potential future impacts to plant success rates at the ISC site -Outline a long-term risk monitoring plan at the ISC within the BMPs with respect to revegetation plan.

Analysis

Step 1: Problem Formulation

Assessment endpoints are measures of the environmental value of the native plant species that will be removed from the ISC site during the construction phase. Vegetation is necessary, especially in the areas near Banaskantha, to protect the fragile desert ecosystem from further environmental degradation. Also, the vegetation is important in reducing the existence of heat sinks. Heat sinks are areas where heat levels rise much higher due to the lack of vegetation. Heat sinks were identified as a potential risk at the NREL revegetation plots (Beatty 2010). This could negatively impact the solar energy technology employed at the ISC by damaging the equipment and increasing maintenance costs. Vegetation would help reduce heat sinks by keeping the soil protected against erosion, with a native grass species capable of reducing the heat level under the panels by several degrees Fahrenheit (Beatty 2010).

Furthermore, deserts, while an ideal location for solar energy complexes, are areas of natural beauty that support a wide range of native plant species. In the areas around the future Ivanpah complex and Kings County complex, the desert landscape stretches on without any buildings in site. While solar projects are needed to help supplement our energy needs, they must be developed with as little intrusion on the natural environment as possible. Removing vegetation from the ISC site could greatly alter the desert ecosystem and aesthetic quality of the region. Furthermore, the complete removal would leave a moonscape that would not have the ability to sustain any life without vegetation.

Steps 2 and 3 Combined: Risk Characterization

Steps two and three have been combined. The reason for this joint step is that a formal ERA would involve the development of both a stressor-response profile and an exposure profile. These are key ingredients to an ERA when chemicals are being tested (Hope 2006). The true nature of an ERA is to measure the potential impacts of chemicals, and then to develop both profiles to help with the risk characterization step. Considering only vegetation is being analyzed, these two profiles are not needed. The subsequent section is thus a combination of analysis and risk characterization within an ERA.

The following endpoints are key attributes that were considered in identifying plant species to revegetate the ISC after array construction. The assessment endpoints were arrived at by evaluating the delicate climate in the Banaskantha region, as well as analyzing the relevant concerns over large solar projects. Previous studies have identified solar projects as having the potential to damage a desert ecosystem. The ISC is the largest planned solar project in the world to date, more than capable negatively impacting the delicate climate of Banaskantha.

Desertification Abatement

The most important aspect of assessment endpoints of native vegetation is the upward trend in the desertification of land in Banaskantha. Desertification is a combination of natural and manmade causes. Rampant overuse of natural resources, over-cultivation, over-irrigation, and deforestation of land under poor natural resource management are the problems that man creates that lead to desertification (Gujarat Ecology Commission 1996). These factors are turning large areas of India into wastelands (Gough 1992). Banaskantha is already on the fringe of the Great Indian Desert, or Thar Desert. Any future sites for the ISC in Banaskantha have to consider that due to spreading desertification, soil depth will be shallow and precipitation will be quite low. The native plant species chosen to re-vegetate the ISC area must be able to survive and provide protection to the topsoil from desertification while also not requiring consistent input of resources.

Desertification is a concern expressed by those that disagree with the spread of large solar projects in desert regions. Construction required at the Ivanpah site for a solar thermal plant would be quite destructive. At the construction phase, the site would require administrative and maintenance buildings, a warehouse for equipment, detention ponds, and a sewage system on site. The site would also regularly be sprayed with herbicide to negate weed growth, which would also inhibit other plant species from growing (Save Ivanpah Valley 2009). These stresses, coupled with the fact that there is no plan yet to revegetate would lead to the spread of desertification. This implies the need for a revegetation plan that will reduce desertification abatement brought on by exhaustive construction activities, as well as a plan that would eliminate the need for regular herbicide application. If the ISC is to choose solar thermal technology, these are important stressors that need to be addressed and mitigated.

Low Biomass Production

The Tribal Energy and Environmental Information Clearinghouse (TEEIC) in the office of Indian energy and economic development cites the increase in the potential for fire and subsequent need for low flammable plants as an issue with respect to ecological resources. The increase of human activities around a large solar project, such as the development of access roads, utility right-of-ways, and the clearing of the land for a fenced solar energy facility, in their analysis, could potentially increase the risk of fire (Tribal Energy and Environmental Information Clearinghouse 2010).

Many of these activities cannot be avoided at the ISC. Due to the risk of fire in the arid to semi-arid regions within Banaskantha, plants chosen for vegetation must pose little risk of spreading fires. These fires would destroy the equipment installed at the ISC. The plants must have very low biomass, meaning they must carry very little extra material, either on the leaves of the plant or dead material that has fallen from the plant (Beatty 2010). This extra material could act as fodder for a spreading wildfire. In many cases, desert plants increase their resilience through consistent burning. Since this is not an option within the ISC, plants must be chosen that pose the lowest risk of wildfire, which are low biomass native grass species.

Competitive Advantage

The TEEIC also sites the spread of invasive vegetation as risk at a solar energy facility in a desert ecosystem. Human activities at the construction phase could deteriorate the ecosystem, making it susceptible to weed growth. This deterioration could create in an imbalance in the ecosystem. Also, the introduction of a remote, fragile desert ecosystem to construction vehicles could accidentally introduce foreign weeds into the site, negatively impacting ecological resources (Tribal Energy and Environmental Information Clearinghouse 2010).

Plants introduced to the area must have the ability to outcompete weeds, while also being native so that the ecosystem balance could be restored. Outcompeting weeds in an area of low rainfall, especially after such a high impact at the construction phase may be a difficult task to accomplish. Despite this fact, some plants chosen for the NREL revegetation study, such as buffalo grass, were chosen due to the ability of the plant to outcompete weeds in low rainfall, whereas in areas of more rainfall, buffalo grass can lose its competitive advantage against weeds (Cook et al. 2005). It will be important to select plants for the ISC that are optimized for survival in the arid to semi-arid regions of Banaskantha so they are best suited to deal with weeds.

Drought Adaptation

A solar energy development programmatic environmental impact statement (PEIS) is being developed by the U.S. Department of Energy (DOE), the Energy Efficiency and Renewable Energy Program (EEREP) and the U.S. Department of the Interior (DOI), Bureau of Land Management (BLM) to assess the potential environmental impacts of large-scale solar facility deployment in Arizona, California, New Mexico, Nevada, Colorado, and Utah. The development of parabolic trough and central tower systems at concentrating solar power plants, or solar thermal, were noted as developments that put a strain on water resources (Solar Energy Development Programmatic EIS Information Center 2010). Water is a major concern, as it is already scant in arid regions. Solar energy facilities would require the use of water resources to operate. Also, the potential for contamination at a solar energy facility from bad management practices could greatly impact water resources (Solar Energy Development Programmatic EIS Information Center 2010).

The use of water resources by the solar energy technology may not be avoidable. This places added stress on selecting plant species that require very little water. This comes as no shock considering the spreading desertification in Banaskantha, where the region receives little rainwater, most of it occurring over a few weeks during monsoon season. Not only does the climate provide very little in the way of precipitation for native vegetation, but human needs for agriculture and everyday life are also a strain on the amount of available water in the region. However, as noted earlier, plants best suited for arid to semi-arid regions may be stronger and better equipped to outcompete weeds.

Grazing Adaptation

India is known to have many free-range grazing animals. The standards for agriculture are much lower in many areas such as Banaskantha. Grazing animals range across lands searching for nourishing plants and water. The mine reclamation study cited grazing animals as a concern for revegetation of the wastelands in Rajasthan. Before maturing to an age strong enough to compete, plant species were eliminated by flocks of grazing animals (Gough et al. 1992). Plant species chosen for the ISC should be non-leguminous, meaning that they do not produce nourishment for animal species. Leguminous species like peas and beans may attract grazing animals more than non-leguminous species. Selection of non-leguminous plants could decrease the amount of grazing animals at the ISC site.

Plant Height

Finally, plants chosen for the revegetation of the ISC will need to have a maximum height that does not interfere with the functionality of either the solar PV panels or the heliostats for a solar thermal plant. This was cited in the NREL study as a concern when selecting species for the revegetation test plots. Species of plant that grew to lower maximum heights were chosen for the NREL study (Beatty 2010). Lower plant heights also can mean less biomass. Low biomass would be good for the prevention of major fires sweeping through the ISC site and limit livestock grazing. In the case of the solar thermal plant, where heliostats can be pole-driven and thus higher off the ground, the plants can reach a higher maximum height. In the case of solar PV, like at the NWTC in Golden, Colorado, the solar panels can be as low as 1-2 feet from the ground at certain points of the day, depending on the angle at which the panels are tracking the sun. Both plant height and the fashion with which the panels or heliostats are mounted are important considerations in deciding plant species for revegetation at the ISC.

Step 4: Risk Mitigation

In the risk mitigation step, species were selected for evaluation as potential revegetation candidates. Three species were selected among a group of potential candidates. Upon selection, the species were used to determine the BMPs that act as a guide to the overall revegetation plan for the ISC.

Species Selection

Seven plant species were initially chosen for evaluation as potential plant species for the ISC revegetation plan. These species were identified as having many of the characteristics that would be necessary to exist in Banaskantha. Also, research from the mine reclamation study in Rajasthan, India helped produce the species list. All species except for Themada triandra and Dichanthium annulatum were listed in the mine reclamation study (Sharma et al. 1997). Out of the seven species chosen for evaluation, three plant species have been identified as candidates for revegetation at the ISC.

The plants were classified based on six categories: growth form, limit desertification; biomass production; competitive advantage against weeds; adapted to drought; adapted to grazing; and low plant height. Seven total species were selected, four grass and three shrub species. The table below describes whether the species selected for the capstone met the criteria in each category (table 3).

Table 3 The plant species evaluated to revegetate the ISC site

Species	Growth Form	Desertification Abatement	Low Biomass Production	Comp. Advantage	Drought Adapted	Grazing Adapted	Plant Height
Themada triandra	Grass	Yes	Yes	Yes	Yes	Yes	No
Dichanthium annulatum	Grass	Yes	Yes	Yes	Yes	Yes	Yes
Cenchrus ciliaris	Grass	Yes	Yes	Yes	Yes	Yes	Yes
Heteropogon contortus	Grass	Yes	Yes	No	Yes	Yes	Yes
Ziziphus nummalaria	Shrub	Yes	Yes	Yes	Yes	Yes	Yes
Grewia tenax	Shrub	Yes	Yes	Yes	Yes	No	No
Capparis decidua	Shrub	Yes	Yes	No	Yes	No	Yes

The species analysis showed that *Themeda triandra, Heteropogon contortus, Grewia tenax,* and, *Capparis decidua* did not meet all criteria. *Themeda* triandra, a grass species that was fine in all categories except for plant height. The plant can grow to a height of 1.5 meters, a height that could restrict the functioning of the solar technology. *Heteropogon contortus* also fit all categories but one, failing to elicit the necessary competitive advantage against weeds of similar characteristics. The plant is suited for slightly rainier areas. The dry Banaskantha region could weaken the plant enough for weeds to take over. *Grewia tenax*, a shrub species, failed to meet both grazing adaptation and plant height. The plant, with a small height and less sturdy physique, would not provide enough of a fence from grazing animals. The other shrub species, *Capparis decidua*, meets all criteria, however the branches are very short-lived, and the tree often looks dead throughout the year. This would also not do a good job protecting the ISC from grazing animals, allowing them to easily pass through the shrubs.

The following sections detail the species that were selected. These were *Dichanthium annulatum, Cenchrus ciliaris,* and *Ziziphus nummalaria.* The first two species are grasses for planting in and around the solar arrays or heliostats while the third species is a shrub that will be utilized to form a perimeter at the ISC site.

Dichanthium Annulatum

Dichanthium Annulatum is native to India, where it is referred to as "hindi grass". It is a tough grass that is known for its ability to grow in many different climates and under harsh conditions. The grass fulfills the criteria that would be required at the ISC with respect to height, biomass, tolerance to grazing and infertile soils, rainfall, and the ability to outcompete weeds.

The grass grows to a height of 3 feet, or 1.0 meter. While it is not known what type of project will be built at the ISC, 3 feet is relatively low to the ground. Only at a maximum height would hindi grass risk shading the panels. Grazing animals could help keep the height of the grass low, however grazing activities would not be encouraged at the ISC due to the valuable solar equipment that will be constructed. Instead, mowing could be used to control grass height.

The plant has very thin stalks with thin white hairs that shoot off from that. The added biomass during the flowering season is not seen as an added risk of fire. It is notorious in areas that are degraded grasslands or wastelands, outcompeting the weeds and other plants in the area. The low biomass and ability to thrive in harsh conditions suggest a tolerance to fire. While it does require seasonal burning to improve fire resistance, the plant can be successful without these burns. Success in arid to semi-arid conditions in Banaskantha and Kachchh is another important characteristic of hindi grass. The plant can withstand a 6-8 month dry season and as little as 300 mm of rainfall in a year. This places it within the rainfall found in both the Banaskantha and Kachchh regions.

One issue contrary to requirements at the ISC is that the plant is not known as a shade tolerant plant. It is adapted to intense solar radiation. However, if it were planted in such as way that it only received limited shade during the day, the plant could still be quite successful. At a solar PV installation where panels would be tracking the sun, the plant would only be shaded for a limited period. The plant, resistant to many harsh conditions, could be expected to succeed despite the shade under solar PV panels. The same would be true at a solar thermal plant if heliostats were pole driven, allowing plenty of space under the mirrors for sunlight at different intervals of the day. Part of the day the grass would be shaded, but as the sun tracks east to west the grass would receive sunlight in all areas.

Zizipus nummalaria

Zizipus nummalaria, or Jharber, is a shrub that is also native to India.

The shrub is well adapted to hot and arid climates found in Banaskantha. It is a drought resistant shrub, and can thrive in heavily grazed areas in arid climates. It produces minimal biomass, and has the ability to regenerate quickly after damage. The shrub is referred to as a multipurpose species, meaning it has edible fruits and leaves, and branches that can be used for fencing, also producing wood that can be used as fuel or for construction of structures.

The shrub, however, is known to grow up to 30 feet (10 meters) in height, and is adapted to intense solar radiation, so shading of the plant would reduce its productivity. However, this is acceptable as the shrub will be used as a perimeter fence to keep grazing animals out. Also, the plant, in the early stages of growth, requires protection against being overgrazed and against weeds, requiring water as well. Grazing animals could overwhelm the shrub and stunt the plant's growth, making it weak against other plants and weeds.

The plant will attract many grazing animals to the area that could harm the equipment at the ISC. Grazing animals could be both a nuisance to construction activities as well as a threat to the functionality of solar energy technologies at the ISC. However, as the shrub grows older, it gets more woody and thorny. The biomass of the plant does increase, but it turns into a very impassable object. The plant could be used as a perimeter to the ISC to help keep grazing animals out of the area, while also providing an environmental benefit to these animals, providing fruits and leaves for foraging. If the shrub is cared for in the early stages of growth, and allowed to grow into a strong and thorny plant, it would provide grazing animals outside of the ISC with nourishment, and protect any plants and equipment on the inside from overgrazing activities.

Cenchrus ciliaris

Cenchrus ciliaris, or "buffelgrass", is a type of grass, much like hindi grass, that is extremely tolerant of harsh conditions. The grass is tolerant of fire, prolonged droughts, disease, grazing, and insects. It is a native grass to India. Buffelgrass has been found in extreme hot and arid conditions as well as tropical, moist conditions. It has been found to be successful in any conditions that it would face in the Banaskantha region of India.

The plant ranges from 0.5 to 4 feet in height, much like hindi grass. It has relatively low biomass, however it has been known in some instances to act as fuel for wildfires (Cook et al. 2005). This would be a problem at the ISC. Any fire at the ISC site would risk damaging the solar energy equipment and costing the plant immensely. This is why it will be used inside of the ISC site perimeter, protected by the access road and perimeter shrubs. This will prevent the spread of fire. Furthermore, not much is known about the sun requirements of buffelgrass. However, the success of the plant has been largely in regions that receive plentiful sunlight so it may have the same requirements as hindi grass.

Buffelgrass, while having some criteria that are counter to the requirements of the ISC, also has many good qualities that make it an option. It is also very similar to hindi grass. The best option may be to have a combination of buffelgrass and hindi grass at the ISC. This would allow the people involved with the revegetation effort to determine which species is best-suited for the amount of sunlight it will require at the ISC, and also the soil and climate.

Step 5: Risk Monitoring

A risk monitoring plan was necessary within the best management practices section to define future follow-up activities that will help the revegetation plan succeed. Research at solar sites is very limited due to recent deployment of these projects. Not enough is known from prior research at both NREL and the mine reclamation site in India as to what the best method for revegetation is. At NREL, the vegetation plots are ongoing, having not yielded any concrete results as of June 2010. As for the mine reclamation sites, the researchers have not returned to the site since completion of the study to measure the success of revegetating the mine wastelands in Rajasthan. This post-rehab monitoring program will be important to measure the success of the three species planted, and will contribute valuable scientific data.

The details of the risk-monitoring plan are explained within the subsequent best management practices section. These mark the specific things that will be monitored individually during the ongoing monitoring program. Any major construction site in a fragile ecosystem should have a risk-monitoring plan to make sure no environmental impacts in the area persist.

Best Management Practices

The BMPs are developed to provide guidance for ISC reclamation and revegetation. These BMPs will also be appropriate for application to other solar array sites developed in arid environments. The BMPs are tools were developed for the ISC in Gujarat, India, based on mine reclamation efforts in India, the NREL revegetation plots, and case studies of the Kings County solar PV project and the Ivanpah solar thermal project. The large ISC site is different than other solar projects, based on the sheer magnitude of the project plan. The amount of land that will be covered could be up to 10 times that of any other solar thermal or solar PV project. Revegetation is thus much more critically needed to reduce environmental degradation in the region. The BMPs are in the order of operation upon completion of the ISC to give revegetation at the site the best opportunity to succeed.

Step 1: Topsoil

Soil in the arid zones of Banaskantha is very shallow, and also can have high salinity concentrations. The low amount of topsoil means that it must be saved during construction so it can be brought back to the site upon completion. It is not clear how much soil will be removed during construction of the ISC. However, six to 12 inches of soil is the optimal amount of soil needed for excavation. When removed from the site, the soil should be stockpiled in an area where it can receive nutrients in the form of water and fertilizer, as well as weed control. This will keep the topsoil in good condition prior to the revegetation of the ISC. Once the topsoil is brought back inside the ISC site, it will give the plants a chance to grow, and also to sustain the topsoil's nutrient content. This will allow the plant species to thrive long-term.

The topsoil will be transported into the ISC site and delivered along the service road that runs around the solar complex perimeter. Delivering topsoil to this road will make it easy for the topsoil to be spread out throughout the solar complex. The Jharder shrubs making up the perimeter fence will require roughly one foot of topsoil while the grass species mix inside the rows of panels or heliostats will require six inches of topsoil. This is low enough to not interfere with shading of the panels, but is enough new topsoil to improve success rates of the planted species.

Step 2: Identifying Plot Areas

The shrub and the grass species will exist in different areas at the ISC site. The grass species must co-exist in and around the panels because of their low maximum height, while the Jharder shrubs will be on the perimeter due to their ability to create a fence of thorny bushes intended to keep out grazing animals. Jharder shrubs will be planted in a perimeter, just outside the service road at the ISC. These plants will be clearly marked and fenced, as they will require more nourishment, such as water and fertilizer, in the early stages because these plants can be fragile when young. It is not until they are 2 years old that they are strong enough to be fully self-sustaining. Jharder shrubs will require more topsoil, so rocks and sand will be removed and replaced with a one-foot layer of topsoil at these plots. This topsoil is from topsoil conserved at the construction phase of the ISC. The stockpiles of topsoil will be on the access road around the perimeter and should be sprayed with an herbicide that does not contain chemicals harmful to wildlife to remain weed free before application to the test plots.

The grass species will exist inside of the rows of heliostats or solar PV panels. These will also be marked clearly and fenced off initially. This will diminish foot traffic from decreasing the chances of the grass species to survive. Six inches of topsoil will be added within these plots, and any large rocks or sand will also be removed from these areas. The six inches of topsoil is enough extra topsoil to vastly improve nutrient content, but also is low enough so that the grass species won't risk growing to a height that will restrict the solar technology from optimal functioning.

Step 3: Species Planting

As noted above, the shrub species Jharder will require watering in the early stages after planting. Once seeds of Jharder are planted, it will be important to consistently water the shrub to ensure its survival. The other two grass seeds must also receive water after planting, but will not require the same amount of water as Jharder. They will only need to be watered the first few days after planting. The Jharder shrubs will have a drip irrigation system in place, which will reduce the amount of evaporation in contrast to a sprinkler system or to hired maintenance workers watering the shrubs. The grass species will not have a drip irrigation system, and will only be watered at the initial planting stage.

The ISC site will be encompassed by a tight perimeter of Jharder shrubs. These shrubs will be fenced initially, protecting them from grazing animals and human harvesting. On the interior of the ISC site, within the rows of solar PV panels or heliostats, depending on the technology employed, a species mix of buffelgrass and hindi grass will be planted. These grass species will be planted in rows between the rows of panels or heliostats to give them maximum sunlight.

There will be 3 foot gaps between the rows of panels or heliostats and the rows of topsoil with the grass species mix. The rows of grass will look like rings for a solar thermal complex, as the mirrors will be focused on a solar tower, and will look like rectangular rows at a solar PV complex where panels are constructed in long rows, tracking the sun throughout the day. Over time, the grass species will travel on their own into the areas in and around the panels or heliostats, further reducing the heat sink. If weeds persist in these areas, maintenance and weed control may be needed.

Step 4: Long-term maintenance

The ERA requires a monitoring program to ensure long-term success of the revegetation plan. These activities will be minimal in the case of the two grass species, but may be somewhat more enduring for the Jharder shrubs. Long-term monitoring and necessary maintenance will help ensure that the plant species are limiting desertification, protecting against fire, outcompeting weeds, have relatively low plant height, and provide protection from grazing animals at the ISC. Finally, the risk-monitoring program will help identify any new issues such as the presence of hazardous materials and bird and wildlife mortality. A checklist for ISC staff has been developed to identify these issues (table 4).

Table 4 The ISC site checklist for the risk-monitoring program

Risk monitoring issue	Comments
Grass species health	
Shrub species health	
Signs of desertification (y/n)	
Signs of fire (y/n)	
Signs of weed growth (y/n)	
Shading of panels (y/n)	
Grazing activities inside the ISC (y/n)	
Hazardous materials (y/n)	
Animal mortality around panels (y/n)	
Animal mortality around access roads (y/n)	
Animal mortality around perimeter (y/n)	

The checklist will help ISC officials identify specifically what problems are persisting at the ISC site. This will supplement the watering program that the Jharder shrubs will need, along with hindi grass and buffelgrass initially. For Jharder, long-term maintenance will mean that water and nutrients will need to be supplied periodically. The shrubs have been planted outside of the complex, and near a service road so that maintenance activities will be facilitated. The success of these plants is important so that grazing animals don't penetrate the complex, degrading the two grass species and solar energy equipment. Furthermore, clearing of any dead branches or leaves is important to remove biomass that could be used to fuel a fire. The branches, as noted before, could be given to local villagers as fuelwood or wood for fences.

The two grass species will not require long-term watering. However, if both species begin showing negative signs, or if invasive weeds are identified, watering should be applied evenly to the plot areas for a period of one week. Watering will be applied 2 hours in the morning and two hours in the evening to reduce evaporation. Even watering is needed as native grasses will compete for water resources (Gough 1992). If either the hindi grass or buffelgrass show signs of success over one another, future revegetation may be needed. The ISC should be replaced with that one species. However, if it is possible, retaining both grass species is beneficial by naturally increasing diversity and improving success against weeds. Finally, the grasses may require trimming if they grow to a height that interferes with solar PV or heliostat functioning.

If Jharder shrubs become degraded, grazing animals could be a threat to the ISC site. If grazing activities become a problem, a chain-link perimeter fence may be needed outside the perimeter of Jharder shrubs. However, other wildlife is a part of the ecosystem and will naturally be a part of the ISC long-term, so any fence must not impact native wildlife, and should be removed if Jharder return to health as identified by ISC officials. Fences have, historically, cut off natural animal corridors and migration paths (Tribal Energy and Environmental Information Clearinghouse 2010). Fences also can increase the chance of low-flying bird collisions, as well as the solar technology itself (Beatty 2010). If bird collisions are noticed during monitoring activities, the ISC will need to identify the problem area and install subsequent bird diverters, or plastic objects that are fluorescent that will divert birds away from dangerous objects (Beatty 2010). If animal mortality is evident, and appears as a result of the solar facility, mitigation measures need be taken. Finally, if there is any hazardous material present either left from construction or from the solar energy technologies, they should be noted and removed immediately using proper hazardous waste removal techniques.

Discussion

The capstone definitively showed that solar projects, similar to many large construction projects, would indeed negatively impact vegetation and would require a revegetation effort once completed. These conclusions were arrived at by following the ERA process, a flexible process for evaluating potential risks to ecological resources, to identify what course the overall analysis should take. CERCLA, as well as fisheries management utilize the ERA process to mitigate the effects of chemical contaminants on ecological resources. However, an ERA can be used, in general, to identify and mitigate environmental impacts from human activity such as from construction at the ISC (Lackey 1998). Activities such as grading of the soil, regular construction traffic, and potential soil sterilization would all lead to impacts on ecological resources (Beatty 2010). These activities can be seen in figure 2, where expansive areas of vegetation are completely cleared.

Background research has identified several impacts to ecological resources that large-scale solar facility deployment could create. The issues specifically relevant to this capstone are desertification, fire risk, invasive weeds and insects, soil depletion and erosion from construction, soil sterilization, bird and wildlife migration interruption and mortality, and introduction of hazardous materials (Solar Energy Development Programmatic EIS Information Center 2010). The information on these impacts is limited, as large-scale solar deployment has only recently been initiated by developed nations. It is vital that deployed solar facilities be monitored carefully to ensure that no unforeseen impacts to ecological resources arise.

The capstone project focused on utilizing the ERA process to identify assessment endpoints for a revegetation effort at the ISC, and drawing analyses from a species selection model like that of NREL and the mine reclamation study. The capstone provided new insight into the benefits of an ERA and a subsequent revegetation plan for a solar complex built in an arid to semi-arid region. The best management practices steps allow future project managers to consider the benefits of vegetation at solar complexes, and give them a conceptual model of how a revegetation effort would be implemented through an ERA.

The result of the species selection was the selection of three different plant species; two grass species and one shrub species that would be used together to support successful vegetation at the ISC site. The hypothetical selection of plant species was made with respect to criteria laid out in the assessment endpoints section. This analysis was arrived at by utilizing the analysis of the mine reclamation wastelands in Rajasthan, India, where plant species were selected with respect to the local climate and harsh conditions that existed (Sharma et al. 1997). The criteria required the selected vegetation at the ISC to fulfill several criteria that would ensure both the solar energy technology and vegetation would be successful without negative impact on one another. These included: protection against fire due to low biomass, protection against desertification while also requiring very little water to sustain plant success, protection against weeds, protection from overgrazing animal activity, and a maximum plant height that will not interfere with solar technology functioning (Beatty 2010).

This was followed by the revegetation plan, which is found within the best management practices guide. The revegetation plan consisted of 3 steps for beginning the revegetation study, and a final step for long-term maintenance. This long-term maintenance section served as the risk-monitoring step. It is an important step for measuring success of the revegetation plan and allowing for necessary changes to be made to ensure long-term success. Also, the risk-monitoring step is important for identifying any new risks to the revegetation plots, to the solar energy technology, or to wildlife.

The best management practices guide is a guide that is for the use of officials planning the development of the ISC. It contains the scientific recommendation of this capstone project for a revegetation plan immediately following the construction of the ISC, and utilizing similar methods as those identified within the analysis section. It also serves as a guide for policy makers, government officials, scientists, students, researchers, and any other stakeholders who are interested in how emerging solar energy technologies may affect the vegetation of an area during the construction phase, the ERA process, the benefits of having native vegetation around large solar energy projects, and how those areas can generate a plan to revegetate if there has been vegetation loss.

Future Research

As noted earlier, previous research on revegetation success in areas where major construction activities have taken place, especially related to solar projects, is very limited. In the case of the mine reclamation study in Rajasthan, India, a revegetation study was conducted by analyzing the requirements of certain species. The study was directed at finding sustainable ways to re-vegetate the wastelands left behind after mining activities. However, there has been no follow-up to the revegetation effort in the region. It is unclear whether the effort was successful or if the combination of extreme conditions and overgrazing activities returned the area to a wasteland. Similarly, the NREL study is too immature for any conclusive results.

Future research on the full effects of solar energy project construction and long-term activities are important, especially with the rapid advance and development of new projects in the U.S. and abroad. The interaction between a solar energy project and fragile desert ecosystems is not known for any part of the world. Solar energy technologies present a great opportunity to reduce CO_2 emissions, as well as our dependence on foreign oil. However, this point is lost if solar energy technologies are negatively affecting the environment.

Further research is also needed on the effects of solar energy technologies on animal species. Any harmful affect on vegetation would certainly mean a high potential for an impact on animal species. In the case of the NREL study, a prairie dog colony had to be relocated before the solar array could be completed (Beatty 2010). Other animal species may require the existence of corridors for migration, such as elk, deer, and bird populations. Initial solar projects have shown to impact the flight of migratory birds, sometimes causing bird collisions (Tribal Energy and Environmental Information Clearinghouse 2010). Also, information on impacts to the soil from contaminants released by a solar facility is not fully known. In the United States, progress in understanding these potential environmental impacts in the form of the programmatic EIS for 6 western states is underway. However, the programmatic environmental impact statement only recently completed the scoping phase (Solar Energy Development Programmatic EIS Information Center 2010).

It is important to keep in mind that this measure for the prairie dog colony was taken at a test site under NREL's direction, which is reputed for having high environmental stewardship standards. It is not known what measures will be taken to safeguard local animal species from harmful impacts elicited by major solar energy projects done by corporations or on a much larger scale like that of the ISC, both at the construction phase and in the long-term.

Summary and Conclusions

The capstone focused on applying current knowledge and studies related to revegetation and solar project construction and synthesized this information in the analysis section. The findings suggest that construction on the scale of the ISC will most certainly negatively impact vegetation. It is not possible to mitigate environmental effects on the fragile ecosystems that large solar projects will inhabit, which makes revegetation activities vital to replenishing the area once construction is completed. Activities that are to ensure the correct construction and implementation of a large solar complex such as grading of land and sterilization of the soil will negatively impact the environment, specifically vegetation.

This places paramount importance on the revegetation plan after construction is completed. The revegetation plan must focus on replanting plant species that are tough and durable, fulfilling a wide range of characteristics with respect to protecting the soil from desertification, having low biomass, protecting the solar energy technology from fire damage, outcompeting weeds, requiring very little water, resistant against overgrazing, and also not growing to a height that will restrict the functioning of a row of solar arrays.

When these species are selected and planting commences, it is important to give these plants an opportunity to succeed in the long-term. This means that placing additional topsoil may be required. Also, planting in a way that can reduce the amount of grazing animals that inhabit the area through a perimeter fence is important. Finally, providing nourishment to the plants at the early stages and in some cases at intervals throughout the revegetation plan will help give the plant species an opportunity to inhabit the solar complex long-term.

The information on long-term revegetation plans is very limited, not just within solar energy projects, but also in the case of the mine reclamation study in Rajasthan, India. Careful monitoring of the revegetation plan will help add to the limited knowledge that exists, and help improve future revegetation efforts.

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